ALUMINUM PIPE CULVERTS

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by

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Joint Highway Research Project

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LAFAYETTE INDIANA

Final Report

ALUMINUM PIPE CULVERTS

BY
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Joint Highway Research Project

Project No: C-36-62D

File No: 9-8-4

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ALUMINUM PIPE CULVERTS

To: G. A. Leonards, Director
Joint Highway Research Project — September 24, 1965

From: H. L. Michael, Associate Director — Project: C-36-62D
Joint Highway Research Project — File: 9-8-4

The attached report "Aluminum Pipe Culverts" has been prepared by Mr. R. H. Brown under the direction of Professor J. F. McLaughlin. The report will be the final report on this project. Any additional research desired in this area will be conducted under a new project.

This study resulted from the request from personnel of the highway commission for information on the use of aluminum pipe. The report is basically informational on the general practices and policies for use of aluminum corrugated culvert pipe.

The report is presented to the Board for information and for comment.

Respectfully submitted,

Harold L Michael

Harold L. Michael, Secretary

HLM:bc

Attachment

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PREFACE

Evaluation of general practices and policies for Aluminum Corrugated Culvert Pipe was begun in February, 1965 under the sponsorship of the Indiana State Highway Department through the Joint Highway Research Project, Purdue University. The project was directed by Dr. J. F. McLaughlin, Assistant Head, School of Civil Engineering. Source material was collected and the report was prepared by Mr. R. H. Brown, Graduate Assistant.

An acknowledgment of appreciation is extended to the numerous State and Federal government agencies who freely supplied materials for this report. The author wishes to extend his thanks also to the following persons for their assistance: Dr. R. B. Johnson and Messrs. J. E. Hittle and S. E. Swami.

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INTRODUCTION

Although aluminum has been used extensively in the construction industry for several decades, its advent into the culvert pipe market is relatively new. In general, engineers are not acquainted with the in-service behavior of aluminum as a culvert material. The performance of corrugated metal pipe (galvanized steel) and reinforced concrete culverts are understood relatively well. The structural, hydraulic and corrosive behavior of these long-used products under a given set of environmental conditions can be predicted with a certain degree of accuracy and confidence.

Design policies and specifications for aluminum corrugated pipe were requested from eleven state highway departments and three Federal Government agencies. Their general practices, policies, opinions and specifications have been reviewed and the findings assimilated in this report. Each agency responded with a variety of information. The U. S. General Services Administration, U. S. Bureau of Public Roads, U. S. Forest Service (California Divisional Office) and the Kaiser Aluminum Sales, Inc. supplemented the material received from the highway departments.

DISCUSSION OF THE PROBLEM

The designer of a culvert is primarily concerned with three engineering parameters:

(1) Hydraulic characteristics of the culvert

(2) Structural behavior of the material

(3) Durability of the material to corrosive chemical attack

Hydraulic

Hydraulic properties are primarily a function of surface characteristics of the material in which the fluid passes over. The surface characteristics of corrugated steel pipe and corrugated aluminum pipe are basically similar for hydraulic parameters. Presently there is no evicence available that would support or dispute this conclusion.

Structural

Kaiser (1)* has provided for the aluminum culvert consumer recommended maximum fill heights for a given pipe size and metal gauge. Their recommendations are for a 2-2/3 inch by 1/2 corrugation and AASHO's H-20 highway loading equivalent. The (6) Bureau of Public Roads approves the fill heights proposed by Kaiser on a project basis.

Spangler's (16) "Moment of Deflection" design criteria and White's (22) "Compression Theory" are generally recognized as the two most reliable approaches for the designing of flexible metal culverts. Based on a 2.5 safety factor, Koepf (11) made use of these two design theories plus the results of data that were collected from his field installations to prepare the design criteria recommended by Kaiser.

* Numbers in parentheses refer to attached references.

Only five states indicated that they had a design policy for determining the gauges of aluminum pipe. Table I summarizes the gauge requirements vs. fill heights for four pipe sizes. California (14) has a blanket specification which doesn't permit fill heights in excess of 10 feet. It is the opinion of the writer that the other reporting states arrived at their design criteria either by using Kaiser's proposed design method or their present design criteria for corrugated steel pipe. Neither Missouri or Michigan provided satisfactory evidence for their conservative designs, and Missouri appeared reluctant to use gauges lighter than number 14.

The Bureau of Public Roads (6) is presently preparing tables for installation criteria for steel and aluminum corrugated metal culvert pipes. Their report should be available in the near future.

Until more information is available, the Kaiser design recommendation is the only sound design criteria at our disposal. Basically it is recognized as being competent and until more supporting evidence flows from research channels, one must rely upon Kaiser's design procedure and his own judgment.

Corrosion

The design of a culvert for structural stability and hydraulic capacities are not the only criteria to consider for an economical design. Because of the complexity of highway systems, the failure of a drainage structure after a short service period from corrosive deterioration can be costly and in many cases dangerous to repair or replace.

Unfortunately, there is no known method by which durability or maintenance free life of a structure can be precisely predetermined. However, there are a few methods available that will allow one to estimate the durability

Table No. 1 - A Comparison of Pipe Gauges, Sizes and Fill Heights

Specifying Agency	Pipe Size	Fill Heights - Feet 1-10	10-15	15-20	20-25	25-30
Kaiser		16*	16	16	16	14
Kentucky		16	16	16	16	14
Michigan	18"	16	16	14	14	14
Missouri		14	14	14	14	12
Oklahoma		16	16	16	16	14
		16	14	14	12	12
		14	14	14	14	12
"	24"	14	12	10	10	10
		14	12	10	10	10
		12	12	12	12	10
		14	14	14	14	12
		14	12	10	10	8
		14	12	12	10	8
"	36"	12	8	8	--	--
		10	10	10	8	8
		12	12	12	10	8
		12	12	10	8	--
		12	12	10	8	8
"	48"	10	8	8	--	--
		10	8	8	--	--
		12	12	10	8	--

*Gage Thickness	Nominal Thickness (Inches)
16	0.060
14	0.075
12	0.105
10	0.135
8	0.164

performance of the structure. Galvanized steel and reinforced concrete pipes have been used for over a half century and therefore, their response to environmental factors can be predicted with a certain degree of accuracy and confidence; e.g. it has been shown that a zinc coating on a steel pipe provides an anodic protection to the core material from electrical deterioration. A deterioration of the zinc coating is not a sign that the coating is inferior but merely indicates that the zinc is being attacked rather than the steel. This galvanized coating is often misconstrued as being an inert material.

Beaton and Stratful (2) relates galvanized metal corrosion primarily to three factors:

(1) The pH of the water passing through the culvert and the pH of the soil in which the culvert is imbedded.

(2) The concentration of commonly found sulfates and chlorides within the soil - fortunately, the relative concentration of these chemicals can be estimated by measuring the electrical resistance of the soil, and it is generally expressed in ohm centimeters, which is the electrical resistance in ohms of a cube of soil that is one centimeter in each direction.

(3) The abrasive potential and the debris carried by the water.

Even though these three factors contribute to corrosion, there are likely other prevailing conditions that may be difficult to isolate that may be conducive to accelerate corrosion. These hidden factors combined with overlooked factors may augment the durability problem.

Chemically, pure aluminum metal reacts more readily with the negative elements than steel. However, aluminum has been used extensively in places where materials are exposed to the weathering elements of nature, and high resistance to corrosion is desired. In fact, one of the big selling points

of aluminum has been "the no paint requirement." Aluminum oxide is the product of reaction when aluminum oxidizes. The oxide and other insoluble aluminum corrosion products creates a highly resistant surface that is formed by a chemisorption process. This surface is usually extremely resistant to normal weathering forces and under most circumstances provides adequate protection against corrosive deterioration.

The problem that we are confronted with is: what process of attack occurs on aluminum when used in the soil and is subjected to the other elements of weathering, plus the environment influence of the stream flow. Aluminum used for culverts is coated with an alloy cladding containing a small addition of zinc to make its solution potential anodic to the aluminum core. The aluminum with this coating complies with ASTM designation alclad 3004-H34.

Forecasting the life expectancy of aluminum culvert pipe at the present stage of development is not much more than a good engineering speculation. Aluminum culverts seem to be effected to some degree by the following factors (1):

(1) Aeration

(2) Electrolyte

(3) Electrical

(4) Galvanic Action

Even though the mechanism of each of these phenomena is fairly well understood, a combination of two, three or more of these factors plus the addition of some miscellaneous unknowns can make a theoretical analysis almost impossible.

A REVIEW OF THE PRESENT POLICIES AND SPECIFICATIONS

The AASHO Committee on Materials have approved the interim specifications for alloy pipe and corrugated aluminum alloy pipe underdrains, which are designated by AASHO M 196-62 I, and AASHO M 197-62 I respectively. These specifications encompass the following items for preparing and testing aluminum culvert pipes and underdrains:

(1) Materials - (The mechanical properties are given in ASTM specification B209 for alloy alclad 3004 with temper H34)

(2) Fabrication

(3) Size and Permissible Variations

(4) Workmanship and Finish

(5) Marking

(6) Inspection and Rejection

(7) Testing

These two specifications now provide highway departments with a guide whereby they may have supplied to them standard quality materials.

The United States General Services Administration has also prepared a specification for Federal use. The requirements set forth in this specification are similar to those outlined in the AASHO interim standard.

The California Division of the U. S. Forest Service (10) has installed a few aluminum pipes. Their design charts are taken from the California Division of Highways for corrugated steel pipe, and they use Federal Specification WW-P-4. They are now considering a new set of tables that will include three inch by one inch corrugations for 36 inch diameters and over. They are also planning to limit deflections to 5 percent from full round and 10 percent elongation from full round. These requirements will be for both aluminum and steel. They have experienced some difficulty with elongations in installing aluminum pipe.

The U. S. Bureau of Public Roads is now engaged in developing fill height tables for installation criteria for steel and aluminum corrugated metal culvert pipes and this new design criteria will be available in the near future. When Federal funds are involved in highway projects, aluminum pipe is covered by AASHO's interim specifications M-196 and M-197. The fill heights proposed by the Kaiser Aluminum Company are approved on a project basis until sufficient information and experience are available on which to formulate definite conclusions as to their reliability.

California

California has been the most progressive state in its efforts to make an evaluation of aluminum pipe culvert. They have sponsored, in cooperation with the Bureau of Public Roads, an investigation to ascertain the performance of aluminum pipe culvert. This investigation included both field test culverts and a laboratory testing investigation. E. F. Nordlin and R. F. Stratfull (4) summarize their findings and conclusions as follows:

> "In general, the data obtained during this investigation agree with the published literature in that aluminum does not seem to be chemically attacked when the pH of the solution is near neutral (7.0). In addition, there is agreement that within the limits of pH 6.0 and 8.0 aluminum should be chemically stable providing there are no other controlling factors such as:
>
> 1. Waters containing heavy metals
> 2. Concentration-cell corrosion
> 3. Stagnant or quiescent water
> 4. Waters containing large quantities of dissolved chemicals
>
> It is a conclusion of this study that these foregoing factors can be successfully controlled by requiring an aluminum culvert protected by means of a bituminous or other approved organic type of coating.

At the pH ranges of 5.0 to 6.0 and 8.0 to 9.0, the chemical stability of aluminum does not appear to be as clearly defined as when the pH range is 6.0 to 8.0. Therefore, whenever aluminum culverts are to be used in the environmental pH ranges of 5.0 to 6.0, and at 8.0 to 9.0, they should also be protectively coated on the basis of pH, alone.

Although this investigation did not determine any direct relationship between the resistivity of a soil or water and the corrosion rate of aluminum, it did indicate resistivity values below which corrosion is more likely to occur.

Published data indicate that at those locations where the in-place soil resistivity were less than 1500 ohm cm, the corrosion of an aluminum pipeline was controlled by the application of cathodic protection. Also, published aluminum culvert test results based on observations over a maximum of 3.5 years of exposure indicated that corrosion from the flow was observed to be almost nil when the in-place soil or the water resistivity had a mean value of approximately 3100 ohm cm. Other reports have indicated that aluminum has been attacked when the water contained more than 181 parts per million of calcium carbonate.

On the basis of the foregoing, it is apparent that a resistivity limitation is required because it is a guide to the relative chemical content of the environment.

Because crossdrains are generally located in the more critical locations, when aluminum is used it should be protectively coated regardless of pH. In addition, the minimum resistivity should not be less than 2000 ohm cm, unless the invert is also paved. This resistivity value implies that the total dissolved solids in the water or soil is approximately 450 parts per million, which can include a total of approximately 125 parts per million of sulfates as SO_4 and chlorides as Cl ions.

In culvert locations which are not as economically critical as cross-drains, changes in the pH, resistivity limits and coating requirements could be made so as to gather further experience with this material.

The test results of this investigation indicate that aluminum is sensitive to abrasion. In fact, the corrosion-inhibiting cladding on the aluminum specimens was penetrated in all of the laboratory corrosion-abrasion tests as would have been the case with zinc coatings on steel. The specimens in this test had a velocity of 5 fps, and the abrading material was Ottawa sand. The field data agree with the laboratory tests that aluminum is not as abrasion resistant as a steel culvert. Therefore, at this time it appears necessary to restrict aluminum from indiscriminate use in streams of high flow velocities containing an abrasive bed load.

This investigation also indicated that flow velocity per sec. may not be a controlling factor in the abrasion process. It appears that the degree of abrasion suffered by a culvert will not only be a function of the velocity, but also of the size, quality, and shape of the bed material. Severe abrasion was observed in the test culvert where the bed contained shattered and angular rocks. Conversely, at another culvert site with similar calculated flow velocities, a minor amount of abrasive destruction was observed where the material consisted of rounded boulders.

On the basis of this accelerated investigation it is estimated that under favorable conditions aluminum may have an anticipated maintenance-free service life of 25 years. However, the durability of the material should be continuously verified so as to confirm or modify the recommendations since they are partially based upon laboratory data."

Illinois

The Illinois Division of Highways (5) has adopted the following policy for aluminum pipe culvert which is outlined in an interoffice memorandum submitted July 3, 1964.

1. Under P. C. concrete pavements, P. C. concrete bases and high type stabilized bases, on which a bituminous concrete surface is constructed, the across road culvert material shall be reinforced concrete culvert pipe.

2. Under flexible bases with bituminous concrete surfaces, designed in accordance with "Interim Policy on Structural Design of Bituminous Pavements in Illinois," the across road culvert material shall be limited to that permitted by the Specifications for Pipe Culverts, Types 1-A through 7-A except that at the option of the District Engineer any one of these materials may be specified.

3. The material for across road pipe culverts under surfaces other than as provided in Items 1 and 2 shall be limited to that permitted by the Specifications for Pipe Culverts, Types 1-A through 7-A. When desired and justified for a specific project, Pipe Culverts, Types 1 through 7, may be used. Concrete culvert pipe may be specified provided the plans and proposal require the Contractor to submit alternate bids for concrete culvert pipe and metal culvert pipe, in which case Federal-aid participation will be based on the lowest price so established.

4. The culvert material for private and field entrances shall be that permitted by the Specifications for Pipe Culverts, Types 1 through 7.

Fill Height Over Top of Pipe	Type
3' or less	Pipe Culverts, Type 1A Pipe Culverts, Type 1
Greater than 3', not exceeding 10'	Pipe Culverts, Type 2A Pipe Culverts, Type 2
Greater than 10', not exceeding 15'	Pipe Culverts, Type 3A Pipe Culverts, Type 3
Greater than 15', not exceeding 20'	Pipe Culverts, Type 4A Pipe Culverts, Type 4
Greater than 20', not exceeding 25'	Pipe Culverts, Type 5A Pipe Culverts, Type 5
Greater than 25', not exceeding 30	Pipe Culverts, Type 6A Pipe Culverts, Type 6
Greater than 30', not exceeding 35'	Pipe Culverts, Type 7A Pipe Culverts, Type 7
Greater than 35"	Pipe Culverts, Special

Pipe Culverts, Type (1, 2, 3, 4, 5, 6, 7)A

Bituminous Coated Corrugated Metal Culvert Pipe
Corrugated Aluminum Alloy Culvert Pipe
Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe

Pipe Culverts, Type 1, 2*, 3*, 4*, 5, 6, 7

Corrugated Aluminum Alliy Culvert Pipe
Corrugated Metal Culvert Pipe
Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe

Kansas

The information received from the Highway Commission of Kansas did not contain a design policy. However, they did send a copy of their special provisions to their standard specifications 1960 edition. This special provision contained minor modifications of the AASHO specification which seemed to be modified merely for their administrative convenience and operations only. No apparent engineering changes were made.

* Extra-strength Clay Pipe included under these types.

Kentucky

The Kentucky Department of Highways (17) has proposed a special provision for corrugated aluminum alloy pipe. This special provision is tentative and is thereby subject to acceptance or rejectance. This special provision provides for the use of certain materials or construction procedures on selected projects only. As of February, 1965, Kentucky (9) had not used any corrugated aluminum pipe. However, a test section was installed in September, 1961. This test area has a continuous flow of water with pH of 3.5. During the latest inspection August, 1964, slight pin holes etching was noticed in the invert of the aluminum pipe. It was their reaction that no significant corrosion was taking place with the aluminum. They qualified their observation by the following statement: "Such etching may be attributed to the filling of pin hole indentations with rust-colored scale deposits which is characteristic of acid-bearing waters." Kentucky has prepared tables for covered heights and gauges for corrugated aluminum pipe. The values in these tables correspond closely to those recommended by Kaiser.

Michigan

The Michigan State Highway Department (12) has a supplemental specification for aluminum culvert pipe. This specification corresponds closely to those recommended by AASHO, and was used on an experimental basis for a project in the upper Peninsula of Michigan. Bids for the project were received on December 3, 1963. No further installations of aluminum alloy pipe has been made pending results from this first installation.

Missouri

The Missouri State Highway Commission (15, 19) design policy provides that the type of culvert pipe used under high type surfaces such as port-

land cement concrete and asphaltic concretes shall be specifically set out in the proposal and only infrequently is metal pipe specified or permitted for such pavements. For those culverts which are located under other surfaces the pipe is specified by group and the contractor is ordinarily given the option of selecting any one or a combination of the pipe types listed in that particular group. Group I is specified for all cross road structures under all roads which have a designed average daily traffic of 400 vehicles per day or more. Group II is specified for all cross road structures under all roads with a designed average daily traffic of less than 400 vehicles per day. This group is also specified for side drainage installation such as entrances and cross overs regardless of traffic or pavement surface type. Group III is specified for locations described under group II when increased corrosion resistance is required.

As previously mentioned, Missouri is rather conservative in their structural designs. They claim that since aluminum pipe does not have fill-carrying capacities equal to those of steel pipe of the same gauge, that they are reluctant to permit use of the same gauge even under the lower fill heights. They contend, that under any loading condition acceptable for aluminum, a steel pipe would be capable of carrying an increased load and thus has a reserve strength or greater safety factor. The increased gauges for aluminum will serve in measure to reduce the wide spread in safety factors and to increase the capacity of aluminum pipe to withstand load stresses to more nearly that of steel pipes. They have recently made a limited number of installations but as of yet no service records are available.

Ohio

The Ohio State Highway Department (8) offers a very limited amount of information on aluminum culvert pipes. They have at present prepared

a supplemental specification for aluminum culverts. In addition to this specification their 1965 edition of their standard specifications will provide for corrugated aluminum alloy pipe underdrains.

Oklahoma

The Department of Highways for Oklahoma (3) have relied entirely on others in writing their specification and as of yet they have had no experience in the use of aluminum culvert pipe. Their minimum thickness requirement for 24 inch and 36 inch diameter pipe is in accordance with their departmental requirements for corrugated galvanized metal pipe.

West Virginia

The State Road Commission of West Virginia (7) is in a similar dilemma as the other states. They have a few installations of aluminum culvert pipe in use but at the present time the culverts have not been in long enough to make a valid report on their performance.

Wisconsin

The State Highway Commission of Wisconsin has formulated the following culvert pipe policy (4): On all freeways and roadways of high pavement type, reinforced concrete pipe are specified. For roadways of intermediate class, the following policy is given: reinforced concrete pipe or corrugated galvanized metal pipe are specified as equal alternates at the contractors option for the culvert channel: if its drainage area is in the upper areas, subject only to intermittent flow of storm water with slight acid contents and its origin is not from bogs and the flow is not subjected to significant erosion and if there is only slight possibilitiès of silting or depositing of soil in the culvert. Reinforced concrete with paved inverts of galvanized metal pipe with bituminous

coating are specified as equal alternates under conditions where the area of flow does not meet the prior criteria. For all other roads, corrugated galvanized steel metal pipe or aluminum alloy pipe or reinforced concrete pipe are specified as equal alternates at the contractors option. Where soil or water is acidic or the soil has a low electrical resistivity, or the culvert is subjected to silting or where there is a potential for aggressive abrasion by sand, gravel or stone in the bed load, consideration should be given to asphalt coatings for the metal. The project engineer may make appropriate changes when they can be documented for engineering reasons.

FIELD INSPECTION

In the early part of 1961 aluminum culverts were first used in Indiana by county highway departments, and by 1964 about half of the counties had purchased and installed a limited number of these culverts. However, since frequent changes are made in county personnel and records were inadequately kept, data that could have been developed from these installations have been lost for evaulation.

In the spring of 1964 a representative of the Kaiser Aluminum Company, Mr. Tom Goby representing the Corrugated Metal (steel) Pipe Association and a representative from the Indiana State Highway Commission inspected nine aluminum culverts and submitted their reports to the Indiana State Highway Department. These reports were brief and the conclusion therein were highly subjective.

On June 9, 1965 Messrs. R. H. Brown and S. A. Swami inspected four culverts of which previous inspection had been made. Since time for inspection was limited, these culverts were selected on the grounds that they would provide an optimum amount of data. The area of interest had received a heavy rain 24 hours prior to inspection, but the streams at inspection time had become clear and had receded to nearly a normal flow level. The pH of the water in each stream was measured with a sensitive Hydrion Paper. Photographs of features which appeared to be of significant interest were taken and a visual inspection was made on each culvert.

1) 36 inch pipe ----- installed 1961*
Location: Pike County ----- County Road No. 38, Patoka
Twp. approximately two miles South of Winslow, Indiana

This culvert carried a small flow estimated at 1/10 cfs., and its flow appeared relatively constant throughout the year with perhaps intervening

* Installation dates were taken from Kaiser's report.

dry periods during seasons of drought. The backfill material appeared to be taken from the roadbed and a poor quality sandstone had been used for riprap. The sandstone was highly discolored with a coating which looked like iron oxide. All material of ferrous composition appeared to be severely oxidized. The runoff area for this creek was from old abanded coal mines and adjacent areas. Figure 1 shows a typical watershed. The pH measured in the field was 3.0. A sample of water was taken and returned for laboratory pH analysis. The pH on this sample was 2.6. The invert of this pipe was severely attacked, as shown by Figure 3. In fact, in many places the material could be removed by hand (Figure 4). The corrosion of this pipe has reached a point that structural failure is impending.

While inspection was being made, a farmer owning the land in which the creek passes provided the inspectors with a brief history of this culvert site. According to him, a concrete masonry bridge at this location failed about six years ago and the county installed a corrugated metal pipe. He claimed that this pipe lasted less than one year and once again the county installed another corrugated pipe. This pipe also failed within a year. Then the aluminum pipe was installed and has lasted now approximately four years.

The pipe was 30 feet in length with a 3% grade. When the flow becomes high, it seems the stream may carry some abrasive materials which cause an abrasive action in the invert of the culvert. It appeared that the upper ends of the corrugation have had some wear from erosion effects.

2) 30 inch pipe ----- installed in 1963
Location: Pike County ----- County Road No. 38, Monroe
Twp. 2 1/2 miles west of Coe

This pipe was installed in a coal mine bog and the watershed is comprised of mining and forest areas. The flow is intermittent. At the time of

inspection, there were still a few small pools of water in the stream bed from the last storm. The pH of the water in these pools was 3.0. Downstream from the culvert about 50 feet was a small pond in which this stream and another adjacent stream drained. The adjacent stream seemed to have a continuous flow of approximately 1/2 cfs. and its pH was 7.0. The pH of the pond where the water entered from the culvert stream was about 4.0. The pH of the entire pond averaged 6.5. It seems likely that the pH of the water passing through the aluminum culvert and the water which pools in the culvert is highly acidic.

If one was to casually inspect this pipe, it would be quite feasible to conclude that there was no apparent corrosive attack. However, when the coal and the muck residues that covered the invert of the pipe with six inches of material were removed, the pipe showed signs of severe attack (Figure 6). In Figure 6 a white crusty material can be seen in the vicinity of the pen point, the region covered with the muck. This white material is probably aluminum oxide and its adherence to the parent material was strong. It was impossible to remove any portion of it by hand to analyze. It appears likely that as long as this material is not subjected to abrasive wear from stream bed materials, the rate of corrosion will be inhibited by this oxide coating. Much valuable information could be gained if this pipe was inspected on a six-month basis for a few years to ascertain how the oxide coating contains the acid attack.

All ferrous materials in this area were severely attacked.

3) 24 inch pipe ----- installed in 1961
Location: Pike County ----- County Road No. 31, Monroe
Twp. 3/4 mile NW of Coe

This pipe is in excellent condition. There is a very slight attack on the aluminum at the water-air-metal interface which could be detected by the feel of the hand. The pH of the stream flow was between 5.5 and 6.0.

The flow appeared to be constant and estimated at 1/4 cfs. The drainage area is from nearby farm lands.

4) 72 inch pipe ----- installed in 1963
Location: Hamilton County ----- three miles West on the Tipton-Hamilton County line and 1/4 mile South from U. S. 31.

This culvert (Figures 7 and 8) replaced an old county bridge and apparently little care was exercised to proper installation procedures. The pipe is warped and a few rocks which lie next to the pipe have made indentations in the metal. The pH of the stream is 6.0. The flow is about 1 cfs. with 10 to 12 inches of water standing in the pipe at all times and there has been a slight attack at the air-water-metal interface. The foreign material visible in Figure 8 is an organic stain and was present on all installations visited. The drainage water for this stream comes from nearby farm lands.

Since the literature related rates of corrosion with soil salt contents and the salt contents can be correlated to soil resistivity, instrumentation for field measurements were obtained from the Geology Department. The operator was not completely familiar with the equipment and data collected was of an inaccurate nature and was discarded. It is the opinion of the writer that if accurate measurements of soil resistivity are desired which are to be meaningful and correlated to the problem at hand, there may be other types of measuring equipment that will yield results more applicable to this problem.

Figure 1 - Drainage area for culvert pipe No. 1. Road on the right of stream is an old coal haul road.

Figure 2 - Down stream end of culvert No. 1. V-shaped notch was cut out during an earlier inspection.

Figure 3 - Close up of the down stream end of culvert No. 1. Note the complete deterioration of the invert.

Figure 4 - Specimen removed by hand from the invert of culvert No. 1.

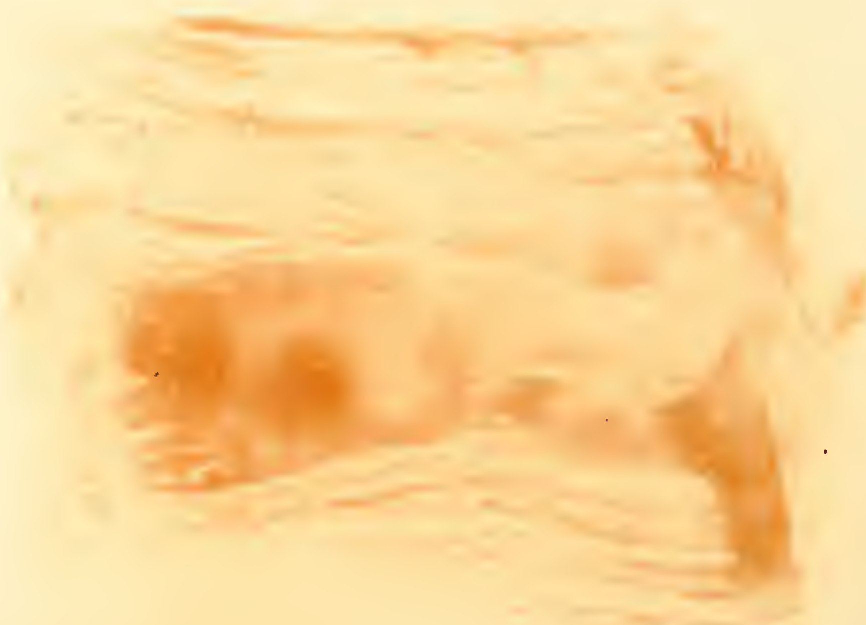

Figure 5 - Typical drainage area for culvert No. 2, which has a high percentage of coal laden material.

Figure 6 - The invert of the down stream end of culvert No. 2.

Figure 7 - A general view of the down stream end of culvert No. 4.

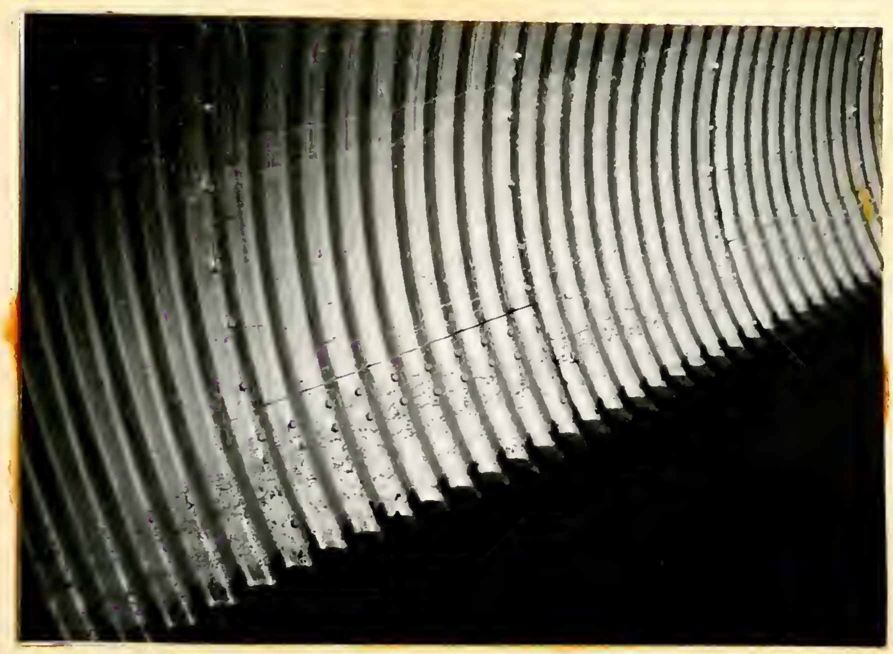

Figure 8 - Close-up view of culvert No. 4. No evidence of deterioration except a light scaling of cladding at the air-water-metal interface.

SUMMARY

California is the only state that is presently in a position to formulate objectively their engineering policy and specification for aluminum corrugated pipe culvert. The results they obtained in their study are indicative of aluminum's behavior when it is used for culverts. However, since the material is subjected to varying environmental factors from section to section of the country, the conclusion set forth in the California report may not be entirely applicable to other sections of the country. A satellite program to the California study may provide information that would be more applicable to conditions prevailing in Indiana.

The U. S. Bureau of Public Roads is presently preparing revised structural design recommendations for both aluminum and steel culverts. Until they are completed the use of Kaiser's structural design recommendations are approved on a project-to-project basis by Public Roads.

The pH contents of materials (water or soil) that are in contact with the aluminum surface have a definite effect on aluminum's durability. Most evidence indicates that difficulty may occur if the pH is outside the 6.0 to 8.0 range.

The salt concentration of soils has in some cases shown a correlation to corrosion rates. Soil resistivity provides a fairly good relative measure of salt content. However, there are not any definite conclusions formulated for the corrosion mechanism.

Aluminum culverts have not been compared and evaluated completely or objectively with their counterparts - corrugated steel pipe and reinforced concrete pipe. There are two approaches that will provide immediate insight into the relative performance of these three materials.

1. Select from the aluminum culverts that have been installed in Indiana a representative sample and monitor systematically their performance.

2. Formulate a satellite study patterned after the California investigation and ascertain what factors are applicable to the Indiana region.

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